University of Alberta

White spruce regeneration and climate-growth relationships in the Peace River lowlands.

by

Peter Andrew Tollestrup

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

Floodplain white spruce sites support some of the most productive forests in northern regions, and the Peace River lowlands support the most extensive old growth white spruce forest in Alberta. Floodplain white spruce along the Peace River has been extensivley logged, but few studies have investigated the origin and succession patterns in these forests. Investigations were conducted on 3 to 25 year old cutblocks that were either scarified and seeded or nonscarified and left for natural regeneration. It was hypothesized that white spruce establish preferentially and grow faster on mineral versus duff or rotted wood substrates. There was continuous recruitment of white spruce ; densities ranged from 200 to 7000 stems/ha. Seedlings establish preferentially on mineral soil, but substrate was not found to significantly influence white spruce growht. The hypothesis that the growth of mature white spruce differed between low and high terrace sites was not substantiated by tree ring analysis.

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TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION AND STUDY AREA DESCRIPTION 1

Literature Cited 5

CHAPTER 2. ESTABLISHMENT SUCCESS OF WHITE SPRUCE ON POST-CLEARCUT FOREST FLOOR SUBSTRATES 6

Introduction 6

Materials and methods 7

Post-clearcut with no scarification 7

Post-clearcut with scarification 8

Data analysis 8

Results 9

Seedling density vs. time since clearcutting 9

Seedling age distributions 9

Seedling establishment success on different substrates 10

Seedling growth rates on different substrate types 12

Discussion 18

Literature Cited 20

CHAPTER 3. CLIMATE-GROWTH RELATIONSHIPS OF FLOODPLAIN AND UPLAND WHITE SPRUCE IN THE PEACE RIVER LOWLANDS 22

Introduction 22

Materials and methods 24

Field sampling: 24

Sample preparation: 24

Data analysis: 25

Results 26

Correlations among mean chronologies: 27

Predam climate correlations: 29

Postdam climate correlations 29

Discussion 33

Literature Cited 36

CHAPTER 4. LIMITATIONS AND RECOMENDATIONS 38

APPENDIX A 40

ORIGIN OF WHITE SPRUCE STANDS ON THE LOWER AND MIDDLE TERRACE LAND TYPES OF THE LOWER PEACE RIVER VALLEY 40

Introduction 40
Literature Cited 43

LIST OF TABLES

TABLE 2-1. RESULTS OF ANALYSIS OF VARIANCE FOR SEEDLING DENSITIES ON DIFFERENT AGES OF CLEARCUTS 9

TABLE 2-2. ANALYSIS OF VARIANCE FOR SUBSTRATE FREQUENCY DATA 10

TABLE 2-3. RESULTS OF STATISTICAL ANALYSIS OF HEIGHT AND DIAMETER INDICES ON FOUR SUBSTRATE TYPES 11

TABLE 2-4. MEANS AND STANDARD ERRORS FOR MEAN ANNUAK INDICES OF HEIGHT (HTX) , DIAMETER (DIX), AND SEEDLING AGE (AGE) 11

TABLE 3-1. TREE RING CHRONOLOGY PARAMETERS FOR THE PERIOD 1910-1992 30

TABLE 3-2. PEARSON CORRELATIONS BETWEEN STANDARD AND RESIDUAL MEAN RING-WIDTH CHRONOLOGIES FOR THE PREDAM PERIOD 1910-1967) 31

TABLE 3-3. PEARSON CORRELATIONS BETWEEN STANDARD AND RESIDUAL MEAN RING-WIDTH CHRONOLOGIES FOR THE POSTDAM PERIOD (1968-1992) 31

TABLE 3-4. SIGNIFICANT ($p<0.05$) PEARSON CORRELATION COEFFICIENTS BETWEEN STANDARD AND RESIDUAL CHRONOLOGIES AND CLIMATE VARIABLES IN THE PREDAM PERIOD (1910-1967) 32

TABLE 3-5. SIGNIFICANT ($p<0.05$) PEARSON CORRELATION COEFFICIENTS BETWEEN STANDARD AND RESIDUAL CHRONOLOGIES AND CLIMATE VARIABLES IN THE POSTDAM PERIOD (1968-1992) 33

LIST OF FIGURES

FIGURE 1-1. MAP OF STUDY AREA 4

FIGURE 2-1. DENSITY (MEAN + S.E.M.) OF WHITE SPRUCE SEEDLINGS ESTIMATED FROM 50 SAMPLE SITES ON RANGING IN AGE FROM 3 TO 25 YEARS 13

FIGURE 2-2. AGE DISTRIBUTION OF NATURALLY REGENERATING WHITE SPRUCE ON NON-SCARIFIED CLEARCUTS RANGING IN AGE FROM 3 TO 25 YEARS 14

FIGURE 2-3. AGE DISTRIBUTION OF REGENERATING WHITE SPRUCE ON SCARIFIED AND SEEDED CLEARCUTS RANGING IN AGE FROM 4 TO 25 YEARS 15

FIGURE 2-4. SUBSTRATE FREQUENCY FOUND BY RANDOM SAMPLING AND WHERE WHITE SPRUCE WERE ESTABLISHED ON 5 CUTBLOCK AGES WITH NO SCARIFICATION 16

FIGURE 2-5. SUBSTRATE FREQUENCY FOUND BY RANDOM SAMPLING AND WHERE WHITE SPRUCE WERE ESTABLISHED ON 3 CUTBLOCK AGES FOLLOWING SCARIFICATION 17

FIGURE 3-1. MEAN DAILY DISCHARGE OF THE PEACE RIVER AS MEASURED AT THE TOWN OF PEACE RIVER FOR THE PRE (1915-1932, 1957-1967) AND POSTDAM (1968-1991) PERIODS 23

FIGURE 3-2. STANDARD (SOLID LINE) AND RESIDUAL (DASHED LINE) TREE-RING CHRONOLOGY 28

FIGURE 3-3. MAXIMUM DISCHARGE OF THE PEACE RIVER AS MEASURED AT THE TOWN OF PEACE RIVER FOR THE MONTHS OF MAY, JUNE, AND JULY FOR THE PERIODS 1915-1932 AND 1957-1991. 35

FIGURE A-1. AGE DISTRIBUTION OF STANDS SAMPLED IN THE PEACE RIVER VALLEY 42

CHAPTER 1. INTRODUCTION AND STUDY AREA DESCRIPTION

With increasing distance northward, old growth white spruce stands are increasingly confined to valley floodplains which have the most mesic and fertile soils (Rowe 1972). The accessibility and productivity of floodplain forests made them early targets for lumber production (Eis and Craigdallie 1983). In southern areas, these types of stands were heavily exploited for lumber and converted to agricultural land. Ecosystem drowning by hydroelectric projects has destroyed floodplains upstream of dams, and downstream sites were disrupted by altered flood regimes (Gill 1973). An increase in commercial activity for timber export led to logging of the stands in more northern regions of Alaska and northwestern Canada, raising concerns about sustainability.

The Lower Peace River Valley floodplains contain some of the largest contiguous stands of old growth white spruce in Alberta and the tallest white spruce tree in the province is reportedly located near Big Slough (Olson 1992). High soil moisture in most floodplain environments normally prevents severe surface fires and the local topography of river meanders, old channels, sloughs, and channel banks provides effective firebreaks (Viereck and Schandelmeier 1980). This has allowed the Peace River lowland stands to reach a level of long-term stability with old-growth characteristics not usually found in the upland boreal forest. Lacate et al (1965) report stands that commonly reached 160 to 240 years of age with origins from fire and vegetation change. Windthrow has also been suggested as a stand origin mechanism (Jeffrey 1961).

The present research was undertaken because commercial logging along the Peace River from the 1950's until the present led to management concerns that these areas may regenerate "poorly", meaning that they may remain in seral stages for long periods of time. A particular concern to environmentalists is the commercial logging of floodplains within Wood Buffalo National Park, the largest forested national park in the world and a UNESCO World Heritage Site. This environmental controversy resulted in a cessation of harvesting in 1991 and concerns for how these cutblocks can be rehabilitated, as many of the clearcuts are so large that sufficient seed rain from residual stands will likely not reach the interior of cutblocks for many years.

In addition to reforestation concerns, the damming of the Peace River in British Columbia in 1968 altered the flood regime of the floodplain white spruce communities. Unfortunately, these forests have been surveyed only to a limited extent (Jeffrey 1961, Lacate et al 1965) and the natural stand origin and succession patterns are poorly documented.

The study area is the Peace River Valley from Tompkins Landing to The Vermilion Chutes and also within Wood Buffalo National Park from Fifth Meridian to the Boyer Rapids (Figure 1-1). Fluvial action is the controlling ecological factor in the lowland. Ongoing erosion and deposition constantly change the landscape, resulting in complex site patterns and abrupt vegetation changes. The major landforms described by Lacate et al (1965) are recent alluvial deposits within the zone of annual flooding,

middle terraces affected only by peak flooding, and the high terrace level of surrounding uplands which are not affected by flooding. The alluvial or low terrace land type consists of point bar deposits, abandoned channel fill, natural levee deposits, and backswamp deposits. The soils are stone free and rich in organic matter with little soil profile development. The middle terrace land type is made up of lacustrine sands and silts overlain by an alluvial cap of up to 1 metre deep. The high terrace land type consists of glaco-lacustrine and deltaic deposits, often associated with sand dunes. The sites of highest productivity are confined to the alluvial and middle terrace land types where the depth of alluvial material is greatest (Lacate et al 1965). The origin of stands on the low terrace was 54% (13 stands) due to fire and 46% (11 stands) due to flooding, while those on the middle terrace were 91% (20 stands) fire origin and 9% (2 stands) due to flooding (see Appendix A for details).

A generalized successional sequence is described by Lacate et al (1965). Fresh alluvial deposits are colonized by a willow stage, then alder and balsam poplar become dominant as sedimentation proceeds and the poplar overstory shades out the shrubs. As the poplar canopy begins to break up and trees die a shrub layer again develops. White spruce can seed in at any time in the sequence and eventually dominates. Following fire a scrub vegetation with varying amounts of willow, balsam poplar, aspen, birch, and alder develops around residual patches of white spruce and balsam poplar. White spruce establishes in the understory and eventually forms a closed canopy with a tall shrub layer of alder and dogwood where tree density is lower. Remnant poplars die before 200 years of age, leaving a pure spruce stand.

The shift in dominance from balsam poplar to white spruce marks the most significant event in the successional sequence (Viereck et al 1993). The first appearance of the feather mosses (Hylocomium splendens and Pleurozium shreberi) is associated with scattered spruce as heavy annual leaf litter prevents their establishment under a deciduous canopy. The rapid growth and slow decomposition of these mosses result in the development of a thick organic layer which in turn results in lower soil temperature and a gradual deterioration of the site.

Commercial logging in Wood Buffalo National Park began in 1951 when rights were granted to harvest mature spruce within Timber Berth 253. From 1955 to 1962 harvesting rights were granted in Timber Berths 367, 396, 378, 402 and 408 as well as in the Big Island block. Between 1960 and 1991 harvesting took place mainly in Timber Berth 408. 2 443 204 m^3 of timber was been removed from the Park. In 1991 harvesting was stopped; approximately 1 102 582 m^3 of harvestable timber remains in Timber Berth 408 (Olsen 1992). Timber Berth 408 is located along the Peace River, includes areas of mature and old growth spruce forest, and is surrounded by aspen and jackpine forested uplands. The limit of the berth is defined by the 800 m elevation level between 112° 45' and 114° 00' West longitude, covering an area of approximately 497 km^2 (Olsen 1992). Clearcutting is the harvest method used in the area, and lack of mature white spruce trees left as a seed source in Timber Berth 408 has been cited as an important reason for the lack of coniferous regeneration (Anonymous 1991). In many areas no stream

buffers were left along watercourses and advanced white spruce growth has been severely damaged during, and subsequent to, logging operations.

In the Fort Vermilion area, floodplain cutblocks were typically smaller and oriented in strips with a buffer of approximately the same width as the cutblocks. Within Timber Berth 408 logging contractors were not required to undertake any regeneration efforts, but outside of the Park logging companies are required to meet minimum regeneration standards set by the Province of Alberta. Mechanical scarification to increase the availability of mineral soil seedbeds followed by broadcast seeding or planting of nursery stock is the dominant technique used to promote regeneration in northern Alberta.

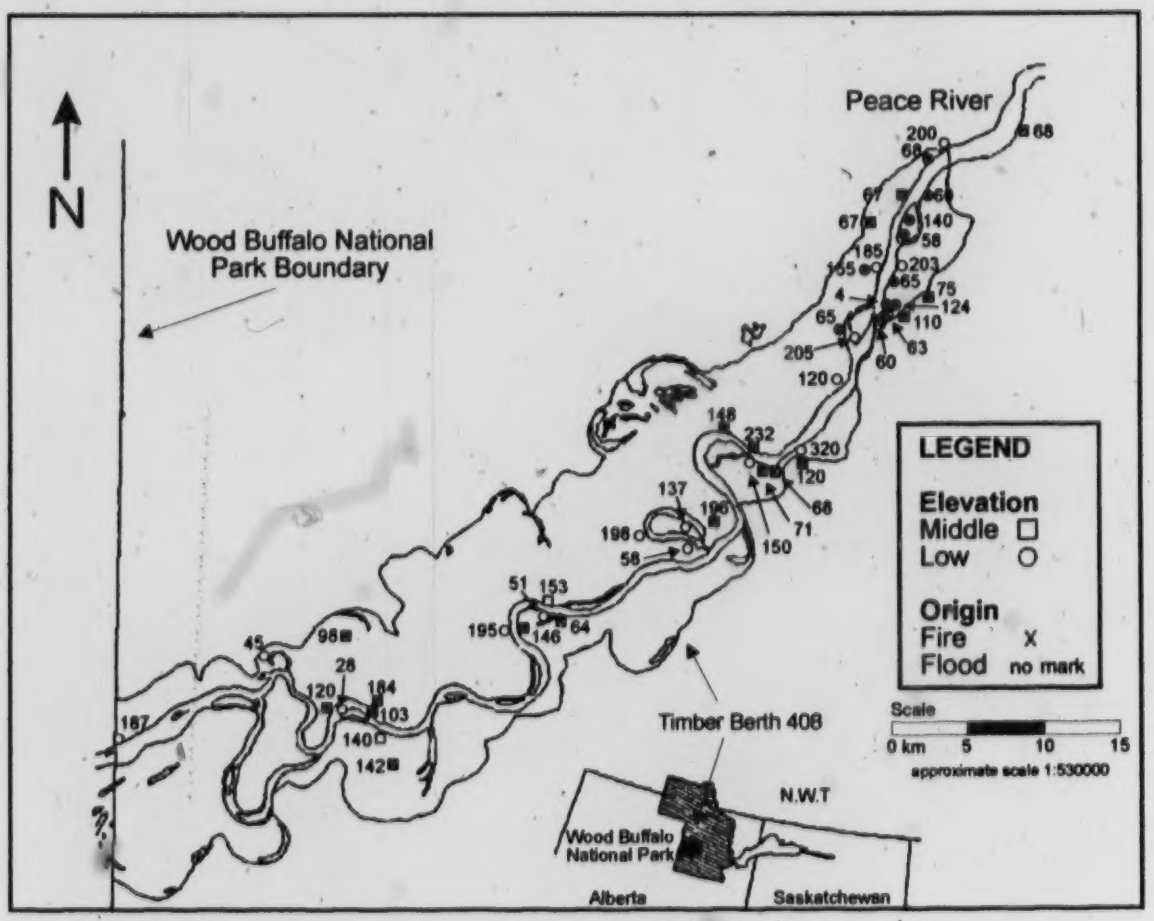

Figure 1-1. Map of study area.

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CHAPTER 2. ESTABLISHMENT SUCCESS OF WHITE SPRUCE ON POST-CLEARCUT FOREST FLOOR SUBSTRATES

Introduction

The many studies on the autecology of North American white spruce (see review with 195 references by Nienstaedt and Zasada 1990) show that regeneration of this commercially important species after harvesting is not highly predictable. Most white spruce ecology studies are for upland landscapes, but with increasing distance northward, highly productive stands become confined to valley floodplains which have the most mesic and fertile soils (Rowe 1972). Van Cleve et al (1993) report that the river floodplains of interior Alaska support some of the most productive forests in the region, and emphasize the role of fluvial processes on the physical and chemical character of floodplain soils in differentiating floodplain from upland forests. Van Cleve et al (1993) also note that fire largely determines the pattern of forest types and successional change on upland landscapes, while flooding determines the path of floodplain forest succession.

There are many studies of white spruce seedling establishment dynamics. White spruce as young as 4 years old have produced cones and seeds (Sutton 1969), and cone production in substantial quantity by 10 to 15 year old trees has been reported, but this is exceptional. Usually seed production does not begin until age 30 or older for most natural stands (Nienstadt and Teich 1972). Good to excellent seed production years (approx. 8000-12000 cones or 250 000 seeds per tree) may occur at intervals from 2 to 12 years; intervening years show low seed production (Nienstadt and Zasada 1990). White spruce is intermediate in tolerance to shade and as such is capable of reproducing under mature stands of either spruce or early succession tree species such as aspen or balsam poplar. Regeneration under established stands commonly occurs on rotted logs (Waldron 1966, Wagg 1964), or feathermosses and their associated organic layers (La Roi and Stringer 1976). Where organic layers are thicker than about 5 to 8 cm seedling establishment is usually unsuccessful (Nienstadt and Zasada 1990). Exposed mineral soil following flooding or windthrow are excellent seedbeds in mature stands (Wagg 1964), but become increasingly rare with time after disturbance due to litter accumulation and increasing plant competition (Lees 1970)

The availability of microsites favorable to seedling establishment is critical to natural regeneration success. Higgenbotham and Tear (1978) reported greater germination rates of seeded white spruce in an uncut stand than on a clearcut and Eis (1967) found greatest initial growth of seeded white spruce under full shade. Higgenbotham and Tear (1978) found greater rates of first year survival where mineral soil was exposed or where competing vegetation had been controlled without mineral soil exposure versus undisturbed control plots. Eis (1967) reported germination of seeded white spruce to be 43 percent on mineral soil compared to only 6 percent on litter, and greater height growth on mineral soil compared to litter after 3 years. Zasada and Grigal (1978) found ten times greater density of seedlings as well as larger

seedlings on mineral compared to organic soil seedbeds. However, Zasada and Grigal (1978) also report a significantly greater density of competing deciduous trees and tall shrubs on scarified versus unscarified surfaces. Eis (1980) reports almost complete mortality in both planted and seeded white spruce on scarified and unscarified alluvial sites after five years and attributed this to vegetative competition. Sutton (1993) documents positive effects of initial site preparation and competing vegetation control on the performance of planted white spruce after thirty years.

The above mentioned studies compared the effects of different site preparation methods applied over large areas on white spruce establishment and growth to that on untreated areas. The objective of this study was to examine white spruce establishment and survival on specific forest floor substrate types found on both clearcut blocks that were left to regenerate naturally (within Park boundaries) and clearcut blocks that were scarified and seeded.

There were two main objectives: (1) to test the hypothesis that white spruce density increases linearly with time and (2) to test the hypothesis that white spruce seedlings establish preferentially and grow faster on mineral soil substrates than on undisturbed sites.

Materials and Methods

Post-clearcut with no scarification:

Within Timber Berth 408 five cutblocks in each of five ages since logging (3, 6, 11, 15, and 25 years) were selected from annual operating plan maps. The age of these clearcuts was verified in the field by determining the age of regenerating deciduous trees, which equals the number of growing seasons since harvest. In each of the 25 cutblocks, fifty 10 m^2 plots (1.78 m radius) were located randomly within approximately 100 m of adjacent white spruce stands and the total number of white spruce in each plot was recorded. Sampling was limited to areas within 100 m of mature spruce stands as that distance is well within the effective limit of white spruce seed dispersal (Rowe 1955, Dobbs 1976, Zasada and Lovig 1983, Greene and Johnson 1996). The substrate at the center point of each plot was classified as one of : mineral soil, duff, rotted wood, or complex (a mixture of mineral soil and duff). An area approximately 10 cm in diameter was evaluated for this classification.

To compare this random point sample of post harvest forest floor substrates with substrates that support white spruce, approximately thirty white spruce seedlings were randomly selected in each cutblock and the rooting medium (the depth at which the first lateral roots appeared) of each seedling was classified as above. Thus two substrate populations were randomly sampled: those available for white spruce establishment and those on which white spruce were found growing. Assuming equal seed rain across all substrate types, a comparison of substrate frequency found at random (forecast frequency) and where white spruce were found growing (observed frequency) will indicate the relative favorability of

each substrate type. For example, a substrate with a greater observed than forcast frequency is more favorable to white spruce establishment than a substrate with a lower observed than forecast frequency.

The height (cm), basal diameter (mm) and age (years determined by node count) were determined for each seedling. The white spruce closest to the center point of the 10 m^2 plot was selected for measuring. If less than thirty of the fifty plots contained white spruce then more randomly located plots were established until thirty were found or the cutblock had been completely searched. White spruce age determined by node count was verified by ring counts done on approximately every fifth tree.

Post-clearcut with scarification:

A second study area was located on the Peace River floodplain in the Fort Vermilion area where all cutblocks received post harvest mechanical scarification treatments. Four cutblocks aged 4 years and five cutblocks aged 10 and 25 years were sampled as outlined above. The four year old area was planted with container stock which were easily distinguished from naturally regenerating white spruce and ignored for the purposes of this study. The ten year old area was aerial seeded with white spruce, while the 25 year old area was hand seeded. As above, all sites fell within 100 m of a seed source at the edge of the cutblock.

Data analysis:

In all cases statistical analyses were conducted separately for non-scarified and scarified sites. The total number of white spruce found in the fifty 10 m^2 plots was divided by 50 and multiplied by 1000 to calculate the density (#stems/ha) of regenerating white spruce on each cutblock. Seedling density data were adjusted by square root transformation to meet normality assumptions prior to a statistical evaluation using a one-way analysis of variance with cutblock age as the source of variation. Analysis of variance was used to determine whether the frequency (expressed as a percent for each cutblock) of white spruce seedlings established on each substrate type differed from the frequency of that substrate type found at random. Sources of variation were cutblock age, population (random or with white spruce) , substrate type, and interactions of cutblock age, population, and substrate. Preliminary analyses of the percent frequency data indicated results were essentially the same for non-transformed and transformed (by arcsine-square root) data and therefore results of non-transformed data analyses are presented. Multiple comparisons using Bonferonni T tests were performed to examine differences between substrate frequencies found at random and supporting white spruce. Differences in substrate effect on height and diameter growth of white spruce seedlings were examined using analysis of variance applied separately to each cutblock age. Seedling height and basal diameter were divided by seedling age to produce indices of mean annual height and diameter increment; sources of variation were substrate, cutblock and substrate by cutblock interaction.

Results

Seedling density vs. time since clearcutting:

Analysis of variance indicated that for non-scarified and scarified cutblocks, white spruce seedling density differed significantly with age of clearcut (Table 2-1). White spruce seedling densities on non-scarified sites were about 1400 seedlings per ha three years after clearcutting (Figure 2-1). Densities six years after clearcutting were only about 200 seedlings per ha. As the clearcuts became older, seedling densities were greater and approached 2000 seedlings per ha by year 25. On scarified sites seedling densities were about 360 per ha after four years, 1200 per ha after 10 years, and over 7000 per ha after 25 years (Figure 2-1).

Table 2-1. Results of analysis of variance for seedling densities on different ages of clearcuts.

	Non-scarified		Scarified	
Source of variation	Degrees of freedom	Pr>F	Degrees of freedom	Pr>F
CUTBLOCK AGE	4	0.045	2	0.0001
Error	20		11	

Seedling age distributions:

In the non-scarified sites the presence of nearly all ages of white spruce indicated continuous recruitment in all cutblock ages. The low frequency of older seedlings suggests few of the younger seedlings will survive (Figure 2-2). The presence of numerous seedlings aged six years and younger on the 11, 15, and 25 year old cutblocks suggests that cone crop periodicity is not likely a factor in the paucity of white spruce regeneration on the 6 year old cutblocks.

The greater frequency of older seedlings in the age distribution for 10-year-old scarified site indicates greater establishment and survival in the years immediately following treatment than in subsequent years (Figure 2-3). The lack of white spruce older than 15 years on the 25 year-old site may be due to flooding as there were thick alluvial deposits post-dating site preparation in that site.

By 25 years the density of seedlings 1 m or greater in height was about 1200/ha on scarified sites. The average age of trees greater than 1 m was 11.5 yrs. Scarification followed by seeding was marginally successful on the 10 year old sites, with about 18% of the trees aged 10 years and thus presumably originating from seeding operations. The average age of trees 1 m or greater in height was 9.7 years, and their density was about 500/ha.

Seedling establishment success on different substrates:

Figure 2-4 shows that on nonscarified sites all substrates supported some seedlings, with the greatest number occurring on duff. For each cutblock age the observed frequency for duff was lower than forecast by a random sample of available substrates, but higher than forecast for complex and mineral soil. Across all cutblock ages 22% of regenerating white spruce were found on duff, which comprised 78% of the available substrates. The complex, mineral soil, and rotted wood substrate types supported 22%, 22%, and 28% of the regenerating white spruce while comprising 6%, 3%, and 14% of the available substrates, respectively. Figure 2-5 shows that on scarified cutblocks most seedlings were found on mineral soil substrates and that the frequency of seedlings found on duff was lower than forecast by random sampling. The observed frequency of seedlings found growing across all cutblock ages on the complex, duff, mineral soil, and rotted wood substrate types was 41%, 5%, 48%, and 6%, compared to forecast frequency of 28%, 26%, 41%, and 5%, respectively. Multiple comparisons using Bonferonni T tests showed that the differences between the observed and forecast frequency were significant for all substrates types on non-scarified sites, but only for duff on scarified sites. The discrepancy between observed and forecast substrate frequency is also indicated by the interaction between substrate type and population, which was statistically significant for scarified (p=0.0001) and non-scarified (p=0.0001) sites (Table 2-2).

Table 2-2. Analysis of variance for the frequency of four substrates found at random and on which a random sample of white spruce were established.

	Non-scarified		Scarified	
Source of variation	Degrees of freedom	Pr>F	Degrees of freedom	Pr>F
CUTBLOCK AGE (A)	4	0.77	2	0.79
POPULATION (P)	1	0.029	1	0.64
BLOCK/A	20	1.000	11	0.99
SUBSTRATE TYPE (S)	3	0.0001	3	0.0001
S*A	12	0.22	6	0.0001
S*P	3	0.0001	3	0.0001
P*A	4	0.065	2	0.79
P*S*A	12	0.0033	6	0.0062
P*BLOCK/A	20	1.000	11	0.99
S*BLOCK/A (Error)	60		33	

Table 2-3. Analysis of variance of height and diameter indices on four substrate types.

Cutblock Age	Source of variation						
	SUBSTRATE Pr>F		CUTBLOCK Pr>F		SUBSTRATE*CUTBLOCK Pr>F		Sample size
Non-scarified	**Height**	**Diameter**	**Height**	**Diameter**	**Height**	**Diameter**	
3	0.73	0.59	0.026	0.21	0.22	0.29	145
6	0.26	0.27	0.002	0.093	0.33	0.002	135
10	0.23	0.23	0.15	0.25	0.16	0.007	155
15	0.0001	0.0003	0.031	0.91	0.90	0.47	152
25	0.048	0.058	0.37	0.37	0.007	0.003	158
Scarified							
4	0.004	0.46	0.0001	0.068	0.99	0.07	102
10	0.271	0.17	0.041	0.001	0.70	0.95	150
25	0.094	0.051	0.98	0.734	0.58	0.55	150

Table 2- 4. Means and standard errors for mean annual indices of height (HTX), diameter (DIX) , and seedling age (Age).

Cutblock Age		Complex	Duff	Mineral soil	Rotted Wood
Non-scarified					
3	HTX	3.99 ± 0.14	4.31 ± 0.14	4.18 ± 0.39	4.07 ± 0.20
	DIX	0.82 ± 0.05	0.76 ± 0.04	0.70 ± 0.09	0.70 ± 0.04
	Age	2.4 ± 0.12	1.8 ± 0.08	2.21 ± 0.19	2.0 ± 0.1
6	HTX	8.15 ± 0.64	8.39 ± 0.38	6.74 ± 0.70	6.58 ± 0.30
	DIX	2.05 ± 0.85	1.17 ± 0.04	0.88 ± 0.07	1.0 ± 1 0.05
	Age	3.75 ± 0.37	4.18 ± 0.15	2.87 ± 0.24	3.74 ± 0.17
10	HTX	9.51 ± 0.42	7.84± 0.50	9.6 ± 0.6	7.93± 0.57
	DIX	1.42 ± 0.08	1.13 ± 0.08	1.3 ± 0.08	1.22 ± 0.08
	Age	7.03 ± 0.36	6.52 ± 0.46	7.08 ± 0.3	5.43 ± 0.42
15	HTX	7.05 ± 0.35	7.36 ± 0.66	8.82 ± 0.54	5.53 ± 0.49
	DIX	1.04 ± 0.06	0.9 ± 0.07	1.28 ± 0.07	0.76 ± 0.07
	Age	7.33 ± 0.47	6.45 ± 0.56	7.62 ± 0.48	4.33 ± 0.56
25	HTX	8.82 ± 0.75	7.29 ± 0.51	11.0 ± 1.43	6.06 ± 0.51
	DIX	1.1 ± 0.09	0.96 ± 0.08	1.33 ± 0.15	0.83 ± 0.08
	Age	9.0 ± 0.61	7.68 ± 0.6	11.85 ± 0.96	5.13 ± 0.78
Scarified					
4	HTX	5.82 ± 0.39	3.55 ± 0.55	5.97 ± 0.21	5.00 ± 0.39
	DIX	1.07 ± 0.07	0.80 ± 0.30	1.22 ± 0.04	1.08 ± 0.09
	Age	2.69 ± 0.24	1.5 ± 0.5	2.56 ± 0.1	3.0 ± 0.27
10	HTX	9.04 ± 0.26	8.22 ± 0.64	9.25 ± 0.26	7.3 ± 0.63
	DIX	1.41 ± 0.05	1.5 ± 0.16	1.45 ± 0.05	1.23 ± 0.06
	Age	7.5 ± 0.23	8.14 ± 0.55	7.64 ± 0.19	7.75 ± 1.11
25	HTX	8.34 ± 0.38	5.96 ± 0.5	9.18 ± 0.65	8.72 ± 2.67
	DIX	1.24 ± 0.04	0.88 ± 0.05	1.29 ± 0.07	1.5 ± 0.54
	Age	6.74 ± 0.32	4.69 ± 0.26	7.93 ±0.51	8 ± 2.65

Seedling growth rates on different substrate types:

In non-scarified sites substrate type was found to be statistically significant for height increment on cutblock ages 15 ($p=0.0001$) and 25 ($p=0.048$), and for mean annual diameter increment on cutblock ages 15 ($p=0.0003$; Table 2-3). Multiple comparisons using Bonferroni T-tests indicated that on nonscarified 15 year old cutblocks mean annual height increment was greater for seedlings found on mineral soil than on complex or rotted wood substrates, while mean annual diameter increment was greater for seedlings found on complex and mineral soil substrates than on rotted wood; seedlings found on mineral soil also had greater mean annual diameter increment than those on duff substrates. On the 25 year old nonscarified cutblocks mean annual height increment was greater for seedlings found on mineral soil than on duff or rotted wood. On scarified sites substrate type was statistically significant for mean annual height increment on cutblock age 4 ($p=0.004$), but multiple comparisons using Bonferroni T-tests did not detect any significant differences among substrate types. This may be due to the small sample size for duff substrates ($n=2$). Substrate type was found to statistically significant for mean annual diameter increment on scarified 25 year old cutblocks ($p=0.05$); multiple comparisons indicated mean annual diameter increment was greater on complex and mineral soil than on duff substrate types.

For all cases, except the 4 year old scarified sites, in which substrate type was found to be statistically significant for mean annual height or diameter increment the mean seedling age was significantly different among substrate types (Table 2-4). In 15 year old non-scarified sites the mean age of seedlings found on rotted wood was 3 ($p<0.0001$), 2 ($p=0.04$), and 3 ($p<0.0001$) years less than that of seedlings found on complex, duff, and mineral soil, respectively. In 25 year old non-scarified sites the mean age of seedlings found on mineral soil was 3 ($p=0.03$), 4 ($p=0.001$) and 6 ($p=<0.0001$) years greater than that of seedlings found on complex, duff, and rotted wood substrate types, respectively. In 25 year old scarified sites the mean age of seedlings found on mineral soil was 3 ($p=0.01$) years greater than that of seedlings found on duff substrates. For those cases in which substrate type was not found to be statistically significant for mean annual height or diameter increment, the mean seedling age was not significantly different between substrate types. Difference in mean annual height and diameter increment therefore may be related to differences in seedling age rather than inherent properties of the substrate, though potential error arising from aging by node count cannot be discounted.

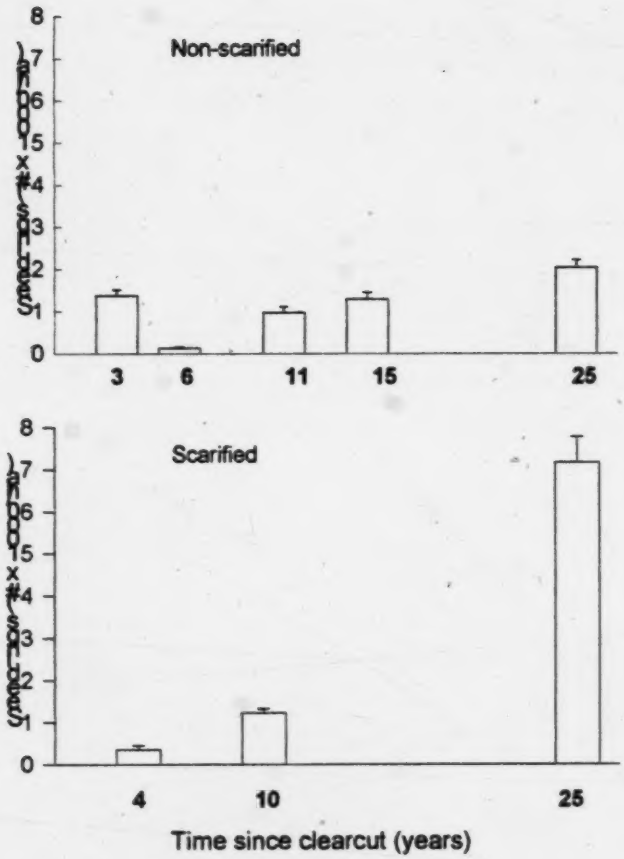

Figure 2-1. Density (mean + S.E.M) of white spruce seedlings estimated from 50 sample sites on ranging in age from 3 to 25 years.

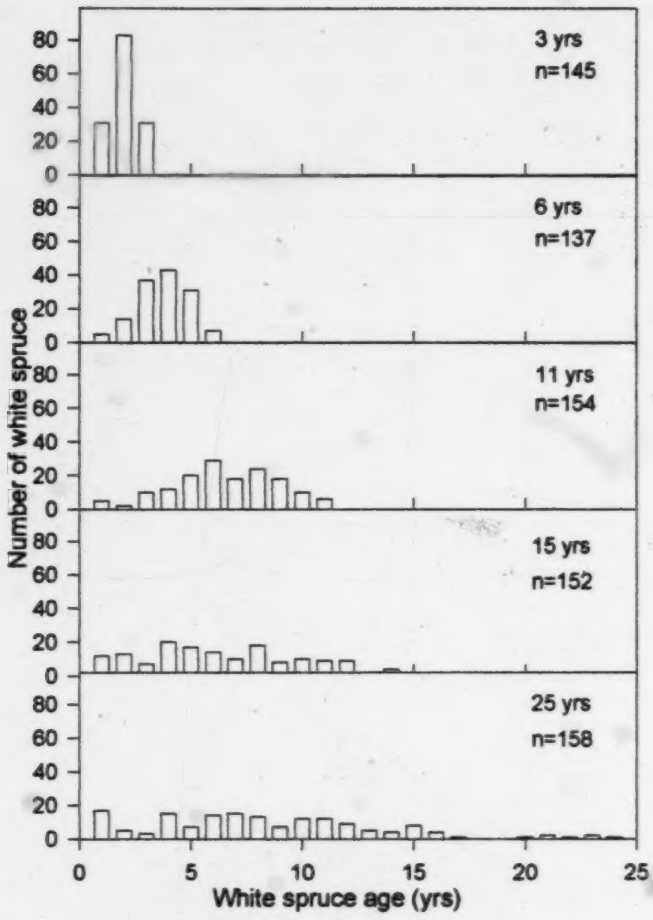

Figure 2-2. Age distribution of naturally regenerating white spruce on non-scarified clearcuts ranging in age from 3 to 25 years.

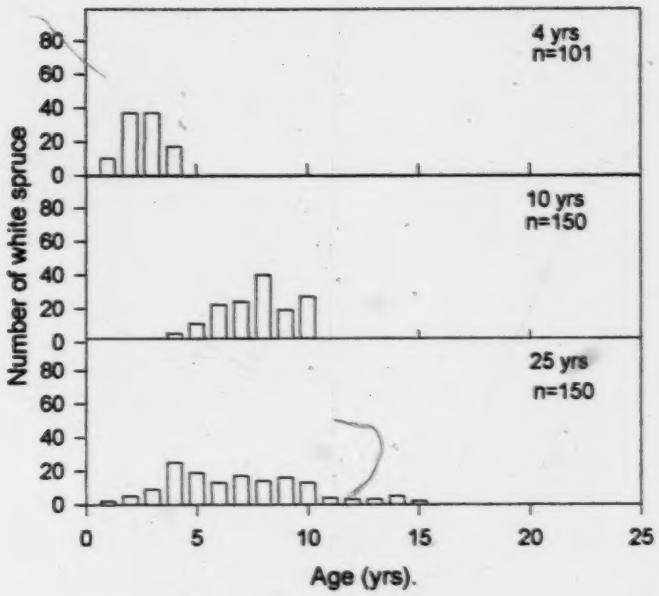

Figure 2-3. Age distribution of regenerating white spruce on scarified and seeded clearcuts ranging in age from 4 to 25 years.

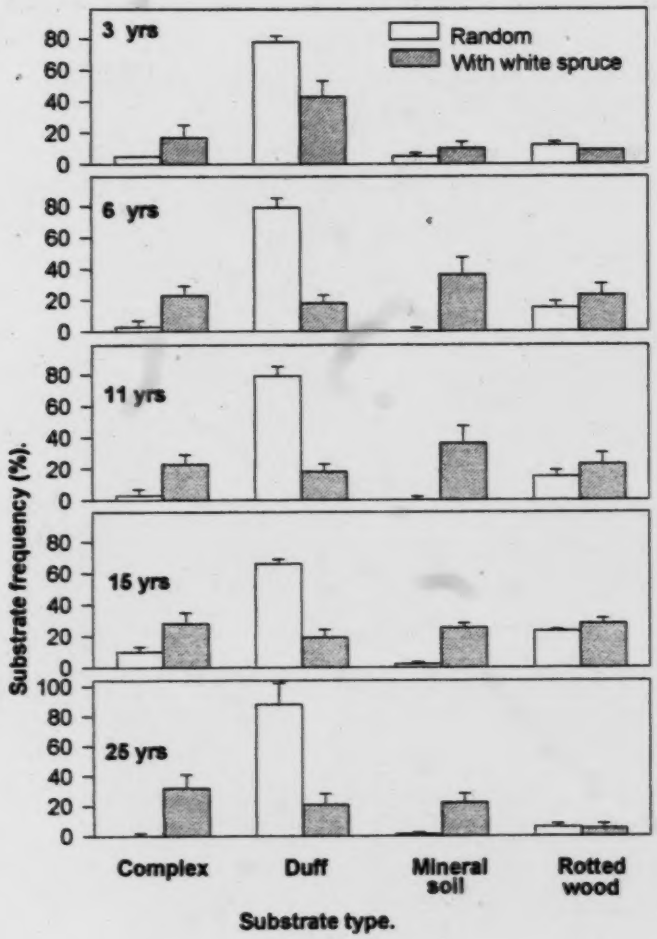

Figure 2-4. Substrate frequency found by random sampling and where white spruce were established on 5 cutblock ages with no scarification.

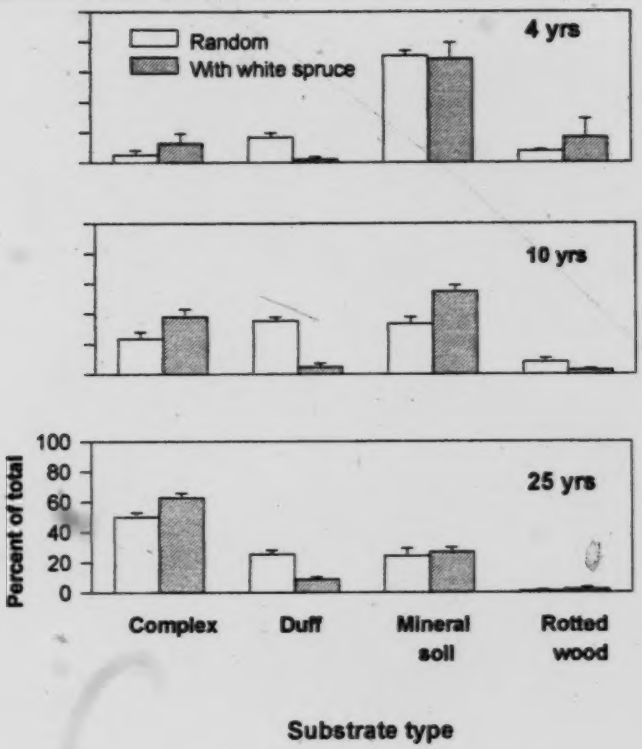

Figure 2-5. Substrate frequency found by random sampling and where white spruce were established on 3 cutblock ages following scarification.

Discussion

The hypothesis that white spruce density increases linearly with time is valid. The total number of white spruce found on clearcuts increased with time since harvest, as would be expected with an adjacent seed source. Continuous recruitment, indicated by the presence of nearly all ages of white spruce on every cutblock age, also suggests a growing population. However, the low number of older white spruce on all cutblock ages suggests mortality is high and that the density of trees reaching maturity will be much lower the total displayed in figure 2-1. The low white spruce density on six year old cutblocks matches observations by Eis (1980), who reported very high mortality on five year old alluvial sites. However, in comparing the density of regenerating white spruce between different cutblock ages the assumption of constant environmental conditions required by chronosequence sampling must be kept in mind.

The statistical significance of substrate type for either mean annual height or diameter increment of white spruce likely results from the interaction of white spruce age and substrate classification. On the 15 and 25 year old nonscarified cutblocks the older trees were taller than the shrub canopy and exhibited vigorous growth not seen on trees still below the shrub canopy. Older trees were classified as growing on mineral soil more often than younger trees and there are several possible reasons for this. Mineral soil may be a superior substrate for seedling survival and thus supports older trees. Downward root extension usually leads to contact with mineral soil and roots formed earlier in other substrates may die back, so the lateral roots closest to the surface are not in the substrate on which the tree originally became established. The likelihood of this happening increases with tree age, biasing the rooting medium classification of older trees.

The lack of any difference in height or diameter growth of white spruce found established on different substrates indicates the success of site preparation treatments reported elsewhere may be attributed to factors such as competing vegetation control rather than a direct effect of substrate type. Lieffers *et al* (1996) reported no difference in height growth between white spruce growing on rotted log and normal forest floor substrates under a mature aspen canopy, and that while diameter growth was initally less on rotted logs there was no difference after the trees had reached breast height. For natural regeneration, initial establishment and survival rather than height or diameter growth is most affected by mineral soil seedbed availability.

Timoney and Robinson (1995) found 27%, 14%, 24%, and 36% of white spruce regeneration in mature white spruce forests on complex, duff, mineral soil, and rotted wood substrates, respectively. Lieffers *et al* (1996) found 32% of white spruce regeneration on rooted logs, while the current study found 41%, 5%, 48%, and 6% of white spruce regeneration on complex, duff, mineral soil, and rotted wood substrates, respectively. The low proportion of white spruce regeneration found on rotted wood in the current study compared to these two reports can be explained by Timoney and Robinson (1995), who also

reported that in early successional stands the preferred substrate for white spruce was mineral soil and that this shifted to decaying wood in later successional stands.

The size and intensity of disturbance and seedbed characteristics are among the most important factors affecting the establishment of species dependant on seed to invade a site (Dix and Swan 1971, Oliver 1981). However, the failure of both biotic and abiotic site classification factors to accurately predict advance conifer regenration using (Kneeshaw and Bergeron 1996) underscores the variability inherent in recruitment. If prefered mineral soil seedbeds are plentiful (Eis 1967) and there is an abundant seed supply (Zasada et al 1992) it is likely that the recruitiment of white spruce will be rapid and heavy, whereas poor seedbeds and/or low seed production at the time of disturbance will likely lead to delayed and sporadic recruitment (Lieffers et al 1996). The latter situtation occurred in Timber Berth 408, where the low level of disturbance associated with winter clearcuting resulted in a low level of mineral soil exposure and thus mainly unfavorable organic substrates for white spruce seedling establishment.

It is important to keep in mind that this study was carried out entirely within the seed rain distance of residual white spruce stands so it represents the maximum regeneration success. In these areas the density of seedlings greater than 1 m in height is about 190, 210, and 520 seedlings/ha on 11, 15, and 25 year old unscarified cutblocks, respectively. The regeneration status documented here likely does not represent that on the interior of large cutblocks which are common in Timber Berth 408. It is apparent that without artificial manipulation many of the harvested areas in Timber Berth 408 will return to preharvest white spruce densities only after a very long time. Intensive site preparation through mechanical scarification or prescribed burning would damage established seedlings and set treated areas back with little guarantee of successful reforestation. Less intensive techniques such as manual scarification followed by planting or transplanting may be more acceptable in a National Park.

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Chapter 3. CLIMATE-GROWTH RELATIONSHIPS OF FLOODPLAIN AND UPLAND WHITE SPRUCE IN THE PEACE RIVER LOWLANDS

Introduction

The dominant role of fluvial processes in the control of forest species composition, production, and nutrient cycling in Alaskan floodplain white spruce forests is documented by Van Cleve et al (1993a). Terrace build up by sedimentation is probably the most important fluvial process in determining the development of floodplain plant communities (Viereck et al 1993), and the periodic renewal of nutrients through sediment deposition is the principle factor in sustaining the high levels of natural ecosystem productivity associated with river floodplains (Van Cleve et al 1993b). Flooding and sediment deposition cause substantial increases in soil temperature (Viereck 1970), leading to higher sustained rates of buried organic layer decomposition (Viereck et al 1993).

The effect of dams on downstream floodplain forests has been investigated by Rood and Heinze-Milne (1989), who report dramatic poplar forest decline downstream of dams on the St. Mary and Waterton Rivers in Southern Alberta. Reilly and Johnson (1982) also document decreased growth of hardwood tree species in the drought dominated environment along the Missouri River following closure of the Garrison Dam. The authors of both of these studies suggest lowering of the water table and the reduction of peak river level as possible causes for forest decline. Stockton and Fritts (1973) found that tree ring records of floodplain white spruce growing on the crests of natural levees in the Peace-Athabasca Delta area reflected the water levels in adjacent river channels. They used this relationship to extend the historical record of water levels in Lake Athabasca. However, little if any research exists on the effects of altered hydrologic regime on the annual growth patterns of boreal floodplain conifers.

Floodplain white spruce stands on the lower Peace River developed in an environment that includes periodic overbank flooding. It is reasonable to hypothesize that flooding and river stage in general influence hydrologic and soil thermal conditions in these stands, which in turn may affect the climate growth-relationship of individual trees. For example, spring flooding would remove any remnant snow cover and rapidly increase soil temperatures in affected areas, or high river stage in summer could elevate the water table in stands adjacent to the river and possibly ameliorate drought conditions. In general, floodplain sites support higher levels of producitvity than upland sites. A reduction in the frequency and magnitude of peak flooding may be deleterious to tree growth on floodplain sites.

Closure of the W.A.C. Bennett Dam in December 1967 has resulted in reduced magnitude and frequency of peak floods as well as altered monthly flow patterns of the Peace River. Figure 3-1 illustrates the dramatic decrease in the average daily discharge at Peace River, particularly in the peak flow months of

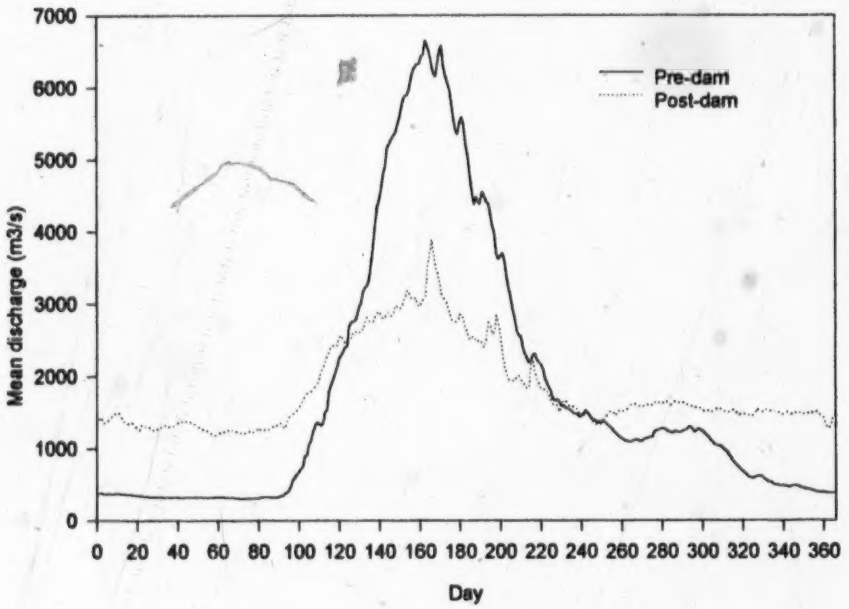

Figure 3-1. Mean daily discharge of the Peace River as measured at the town of Peace River for the pre (1915-1932, 1957-1967) and postdam (1968-1991) periods..

May through July. Junk et al (1989) suggest that a decrease in flooding exerts strong pressure on plant communities to move to the next stage of succession. In the case of northern floodplain white spruce, the next successional stage is marked by gradual site deterioration due to colder soils and a shift from closed white spruce stands to open black spruce stands (Viereck et al 1993).

The objective of this study was to test, through tree-ring analysis the hypothesis that: a) the climate-growth relationship of white spruce on the low terrace level (affected by flooding) was different from that of white spruce at higher terrace levels (not affected by flooding) and b) the climate-growth relationships of white spruce on the low terrace level has changed markedly between pre and postdam periods.

Materials and Methods

Field sampling:

During the summer of 1993 two low terrace stands and two upland stands in Wood Buffalo National Park were sampled. An additional two low terrace stands near Fort Vermilion were sampled in August of 1994. Two increment cores were taken from each of ten randomly selected canopy dominant white spruce within each stand.

Sample preparation:

Sample preparation to determine the annual growth of sampled white spruce followed procedures for ring width and densitometric analysis using DENDROSCAN, a custom software package (Campbell and Varem-Sanders (1994)). The increment cores were mounted on slotted wood blocks with protein based, water soluble glue, and then pressed and oven dried at 700C. A twin-blade table saw with a specialized jig was used to make an inside cut such that a sub-sample of the increment core (0.7 mm thick) was left suspended between the two cuts. This sub-sample was then removed using a razor knife. The removed samples were wrapped in fine nylon mesh to facilitate handling during extraction procedures.

Three extractions were performed on all samples with a soxleht extraction apparatus. The first was for 24 hours with hot water to remove mounting glue and water soluble resins and salts. The second was for 8 hours with an organic solvent solution (ethanol and cyclohexane, 70/30 by volume) to remove higher molecular weight aliphatic and aromatic resins. The third extraction was for 4 hours with hot water to remove the solvent. Following extraction, the samples were placed in a curved press and oven dried for 48 hours at 700C. The press was used to impose a lengthwise curvature on the samples to eliminate parallax in the X-ray chamber. The samples were then arranged on a thin acetate sheet (to make handling easier) placed on a curved aluminum plate. Under darkroom conditions just prior to placement in the X-

ray chamber, raw film was slipped under the acetate and a calibration wedge added to the previously arranged samples. The aluminum plate was then placed in the X-ray chamber and exposed. The X-ray negatives were used to make photographic prints, which in turn were digitally scanned for analysis by DENDROSCAN.

Data analysis:

Cross dating (Fritts 1976) is the process of aligning the sequence of annual tree ring measurements among sampled trees to ensure errors in dating due to false or missing rings are eliminated. This was performed among cores from the same tree, among trees from the same site, and finally among sites by comparing ring width graphs. This was done by computer with editing features of DENDROSCAN, manually overlaying hardcopy graphs on a light table, and with the aid of the COFECHA subroutine within the ITRDBLIB program (Grissino-Mayer et al 1992). The COFECHA subroutine provides data quality control by verifying crossdating and indicating potential problems. Segments of individual tree-ring series which correlate poorly with the mean of all other series or which correlate higher at some position other than as dated are flagged. Single year widths which are 3.0 standard deviations above or 4.5 standard deviations below the mean of all other series for that year are also flagged. Flagged segments or individual years can be checked manually for false or missing rings or for measurement error. An iterative process of crossdating and verification was followed until all potential problems were thoroughly investigated.

Standardization is the process of estimating and hence removing the growth trend from each individual tree-ring series to emphasize fluctuations caused by climatic factors. The resulting series have a mean of zero, which is necessary so that when averaging several series together the resultant mean ring-width series is not dominated by a few samples with either large or small ring widths. The ARSTAN subroutine within the ITRDBLIB program (Grissino-Mayer et al 1992) was used to create standardized and residual mean ring-width chronologies for each site and to generate descriptive parameters for each site chronology. The growth trends were removed from each individual tree-ring series by fitting either a negative exponential or straight line function and producing a detrended ring-width index series for each by dividing every observed ring width by the ring width predicted by the function (Fritts 1976, Cook et al 1990). Residual chronologies were produced by removing the autoregressive component of the detrended series by fitting low order autoregressive models to the data and then subtracting this from the detrended series (Cook 1985). The mean chronologies for each site were calculated as the biweight robust mean value of the detrended individual tree-ring series. Removal of the autoregressive component from the residual chronology may provide more reliable correlations with climate in the growth year than those found by using the standard chronology. However, the presence of autocorrelation in weather patterns due to persistence at the interannual scale might also cause autocorrelation of tree ring widths. Removal of autocorrelation from these climatic sources would reduce the correlation between climate and ring

widths (Larson and MacDonald 1995). Therefore, both the standard and residual chronologies are used in the analyses. The statistical quality of each site chronology was assessed using the Expressed Population Signal (EPS) statistic which compares the agreement of a given chronology with a hypothetical population value (Cook et al 1990).

The subroutine MET within the ITRDBLIB program (Grissino-Mayer et al 1992) was used to compute a regionally averaged mean monthly temperature and total monthly precipitation record from AES weather stations at Fort Vermilion, Fort Chipewyan, and Fort Smith for the period 1910-1992. Regionally averaged data are generally superior to single station data in isolated regions (Blasing et al 1981) and were also desirable because each station had missing data, whereas the regional average was complete. Pearson correlations were calculated for the 1910-1967 (predam) and 1968-1992 (postdam) periods among the standard and residual mean ring-width chronologies for each site and between the standard normal variates of climate variables (predictors) and mean ring-width chronologies (Fritts 1976). The predictors used were the mean monthly temperature and total monthly precipitation for 18 months from April of the year prior to growth to September of the year of growth.

Results

Sites 941 and 942 were in the Fort Vermilion area and were both located on the low terrace level (Table 3-1). All other sites were inside Wood Buffalo National Park. Sites 183 and 1200 were also on the low terrace level, site 334 was on the middle terrace level, and site 10 was located on the upland. Wigely et al (1984) suggest an Expressed Population Signal (EPS) value of 0.85 as a threshold for chronologies to be of sufficient quality for use in climatic reconstruction. Only one site (334) has EPS values substantially lower than 0.85, and as the present study is confined to the period of available climate data (i.e.; no extrapolation is performed) it was assumed that all the chronologies were of sufficient quality to include in the correlation analysis. Figure 3-2 shows the standard and residual ring-width chronologies for all sites. The six tree ring chronologies had similar decadal-scale variations in ring-widths and crossdating was facilitated by a number of marker years such as the narrow rings in 1980, 1970, and 1920. The standard and residual chronologies were generally similar, although the residual chronologies showed a greater amplitude of variation, as reflected in the greater mean sensitivity of residual versus standard mean ring-width chronologies. Autoregressive modeling was effective in removing most of the first-order autocorrelation from the standard chronologies.

Correlations among mean chronologies:

The standard and residual mean ring-width chronologies for all six sites are significantly correlated in the predam period and the majority of sites are significantly correlated in the postdam period (Tables 3-2 and 3-3). Of note are the significant correlations between the mean ring-width chronologies from the upland site (10), the middle terrace site (334) and all of the low terrace level sites in both pre and postdam periods for both chronology types.

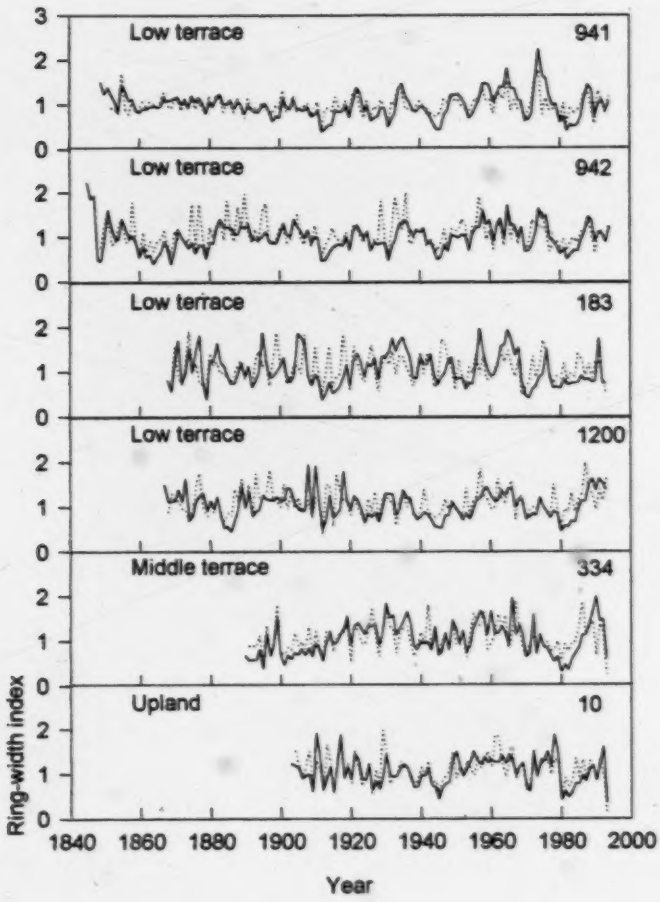

Figure 3-2. Standard (solid line) and residual (dashed line) tree-ring chronologies.

Predam climate correlations:

Table 3-4 shows the significant correlations among standard and residual mean ring-width chronologies and climate data in the predam period. All sites except 183 showed significant correlations with August precipitation of the growth year for both standard and residual chronology types. Four out of six standard and five out of six residual mean chronologies were significantly correlated with precipitation in the previous September. All six residual mean chronologies and two standard mean ring-width chronologies were significantly correlated with June precipitation in the growth year in the predam period. Few significant correlations were found between the mean ring-width chronologies and mean monthly temperature variables and none showed consistent correlations for either standard or residual mean ring-width chronologies.

Postdam climate correlations:

In the postdam period there were no consistent predictors significantly correlated with the mean ring-width chronologies for all sites (table 3-5). Precipitation in June of the growth year was significantly correlated with the standard chronologies from sites 10 and 942 and with the residual chronologies from sites 10, 942, and 183. As in the predam period, few significant correlations were found between the mean ring-width chronologies and mean monthly temperature variables and none showed consistent correlations for both standard and residual mean ring-width chronologies.

Table 3-1. Tree ring chronology parameters for the period 1910-1992.

	Site					
	941	942	183	1200	334	10
Number of trees	9	7	7	9	5	6
Number of radii	15	11	12	18	8	8
Raw ring widths						
Mean ring width (mm)	1.43	1.50	1.15	1.32	1.69	1.44
Standard error (mm)	0.065	0.069	0.098	0.077	0.095	0.074
Standard chronology						
Mean sensitivity	0.18	0.21	0.22	0.17	0.25	0.23
First-order auotcorrelation	0.68	0.56	0.63	0.67	0.62	0.42
Agreement with population chronology (EPS)	0.91	0.83	0.90	0.91	0.73	0.84
Residual chronology						
Mean sensitivity	0.23	0.24	0.26	0.21	0.30	0.28
First-order autocorrelation	0.03	0.004	0.01	0.03	0.10	0.09
Agreement with population chronology (EPS)	0.90	0.84	.089	0.90	0.75	0.87

Table 3-2. Pearson correlations between standard and residual mean ring-width chronologies for the predam period (1910-1967).

	Standard mean chronologies					Residual mean chronologies				
	941	942	183	1200	334	941	942	183	1200	334
941	--					--				
942	0.88	--				0.85	--			
183	0.60	0.58	--			0.58	0.50	--		
1200	0.66	0.60	0.60	--		0.58	0.49	0.66	--	
334	0.35	0.35	0.55	0.61	--	0.33	0.28	0.61	0.60	--
10	0.72	0.64	0.46	0.79	0.55	0.66	0.57	0.60	0.71	0.63

Note: all correlations are significant at $p<0.05$.

Table 3-3. Pearson correlations between standard and residual mean ring-width chronologies for the postdam period (1968-1992).

	Standard mean chronologies					Residual mean chronologies				
	941	942	183	1200	334	941	942	183	1200	334
941	--					--				
942	0.93	--				0.86	--			
183	0.33*	0.41	--			0.30*	0.20*	--		
1200	0.39*	0.61	0.38*	--		0.49	0.58	0.45	--	
334	0.39	0.61	0.46	0.94	--	0.52	0.61	0.48	0.88	--
10	0.74	0.83	0.52	0.58	0.58	0.57	0.69	0.44	0.69	0.67

Note: all correlations are significant at $p<0.05$ except *.

Table 3-4. Significant ($p<0.05$) Pearson correlation coefficients between standard and residual mean ring width chronologies and climate variables in the predam period (1910-1967).

Standard mean chronologies			Residual mean chronologies	
Site	Climate variable	r	Climate variable	r
941	August precip. in growth year	0.43	August precip. in growth year	0.41
	August precip. in previous year	0.32	February temp. in growth year	-0.31
	October precip. in previous year	0.32	June precip. in growth year	0.33
			May precip. in growth year	0.29
			July precip. in growth year	0.27
			October precip. in previous year	0.26
			September precip. in previous year	0.26
			December precip. in previous year	-0.26
			March temp. in growth year	-0.25
942	October precip. in previous year	0.36	February temp. in growth year	0.40
	August precip. in growth year	0.35	August precip. in growth year	0.37
	July precip. in growth year	0.29	June precip. in growth year	0.32
			April temp. in growth year	0.32
			October precip. in previous year	0.26
				0.39
183	September precip. in previous year	0.42	September precip. in previous year	
	July temp. in growth year	0.38	June precip. in growth year	0.33
	July temp. in previous year	0.35		
1200	August precip. in growth year	0.37	August precip. in growth year	0.36
	September precip. in previous year	0.37	September precip. in previous year	0.36
	August precip. in previous year	0.33	June precip. in growth year	0.31
	June precip. in growth year	0.28		
	June precip. in previous year	0.27		
334	September precip. in previous year	0.39	August precip. in growth year	0.35
	August precip. in growth year	0.28	September precip. in previous year	0.33
			February temp. in growth year	-0.31
			June precip. in growth year	0.30
			April temp. in previous year	-0.29
10	August precip. in growth year	0.52	August precip. in growth year	0.45
	September precip. in previous year	0.41	June precip. in growth year	0.38
	August precip. in previous year	0.34	September precip. in previous year	0.31
	June precip. in growth year	0.33	February temp. in growth year	-0.30
			July precip. in growth year	0.28

Table 3-5. Significant ($p<0.05$) Pearson correlation coefficients between standard and residual chronologies and climate variables in the postdam period (1968-1992).

Standard mean chronologies			Residual mean chronologies	
Site	Climate variable	r	Climate variable	r
941	July precip. in previous year	0.45	July precip. in growth year	0.61
	June precip. in previous year	0.43	March precip. in growth year	0.48
			June precip. in growth year	0.43
942	June precip. in growth year	0.42	March precip.. in growth year	0.40
	June precip. in previous year	0.40	June precip. in growth year	0.39
183	April precip. in previous year	-0.46	August precip. in previous year	0.50
	January precip. in growth year	0.42	June precip. in growth year	0.47
	June temp. in growth year	-0.40	December precip. in previous year	0.45
	September precip. in growth year	-0.39	September precip. in growth year	-0.41
1200	November precip. in previous year	0.57	April precip. in previous year	-0.40
	November temp. in previous year	-0.45		
	October temp. in previous year	-0.40		
334	November precip. in previous year	0.57	no significant correlations	
	March precip. in growth year	0.45		
	November temp. in previous year	-0.40		
10	November precip. in previous year	0.48	June precip. in growth year	0.51
	June precip. in growth year	0.47	November precip. in previous year	0.46
	March precip. in growth year	0.41	April precip. in previous year	-0.44
	April precip. in previous year	-0.40		

Discussion

Significant positive correlations among the mean ring-width chronologies in both the pre and postdam periods indicate that white spruce growing on low terrace and upland sites responded to their environments in a similar manner. Significant correlations between all mean ring-width chronologies and a few climatic predictors, particularly precipitation in August of the growth year, also indicates a synchronous response among all sites during the predam period. These results suggest that any potential effect of periodic flooding on the radial growth of low terrace level white spruce is not sufficient to override the influence of regional climate. Therefore, changes in the magnitude and frequency of flooding caused by upstream impoundment are not likely to be detectable in the tree-ring record of low terrace white spruce, as indicated by the significant positive correlations between the mean ring-width chronologies from all of the low terrace level sites and the middle terrace level and upland sites in the postdam period.

Figure 3-3 illustrates another possible reason that hydrologic control may not have resulted in any detectable changes in the climate-growth relationships of floodplain white spruce. Although the maximum discharge for May through July are generally lower in the postdam period than in the predam period, the values for June 1972, July 1982, and June 1990 are in the same range as the peak maximum discharge years in the predam period.

A greater number or different selection of sites may show different results, but it is likely that the immediate effect of flooding on the growth of mature white spruce is negligible, and long term effects will be difficult to separate from ongoing successional change. A postdam period of 25 years, as in the current study, may not be long enough for the impact of upstream hydrologic control to be exressed in mature spruce forests. The increased productivity of floodplain forests relative to upland forests is a result of fluvial processes which affect succession and soil development over several hundred years. The impact of fluvial processes decreases as terrace elevation increases, and by the time a mature white spruce forest has developed only extreme events have a noticeable effect.

The potential effects of flood regime change would be more appropriately investigated on lower elevation landforms and with earlier successional species such as balsam poplar which are more closely tied to fluvial processes . Reilly and Johnson (1982) and Rood and Heinze-Milne (1989) demonstrated marked effects of upstream hydrologic control on hardwood floodplain species. Another approach would be to examine the age class distributions of white spruce on different terrace levels relative to the occurrence of flooding events.

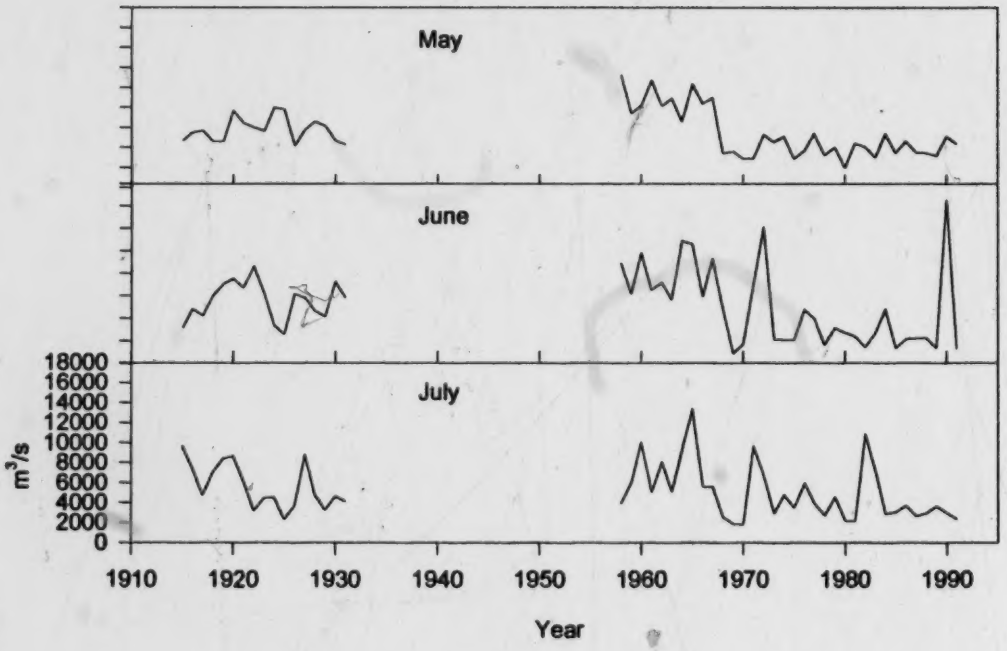

Figure 3-3. Maximum discharge of the Peace River as measured at the town of Peace River for the months of May, June, and July for the periods 1915-1932 and 1957-1991

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CHAPTER 4. GENERAL DISCUSSION

The mandate of National Parks to protect for all time representative areas of Canadian significance must be the basis for any recommendations regarding potential intervention in Timber Berth 408. Applying commercial forestry regeneration standards is inappropriate in a national park due to the short term disruption of natural processes caused by site preparation techniques, and in the long term the large financial investment associated with commercial reforestation may lead to the perpetuation of principles external to Parks policy (further intervention to protect the investment). The vegetative recovery that has taken place to date is part of a natural process that will eventually lead to ecological equilibrium and any intervention undertaken will disrupt this naturally functioning system. Planting of robust nursery stock produced from local seed collected from a wide range of trees is one option for hastening a return to coniferous forest cover. Transplanting white spruce seedlings from abundantly stocked areas near cutblock edges to lesser stocked areas in cutblock interiors is another.

Execution of the methodology and subsequent data analyses described in the preceding chapters has lead to recognition of limitations in the experimental design and the development of related hypotheses for further study. The hypothesis relating to white spruce density increasing with time since harvest would have been more appropriately addressed using standard regeneration survey methods applied over greater areas than were examined in this study. A regularly spaced grid of sample plots distributed across entire cutblocks would provide a more complete representation of the density of white spruce regeneration and also allow for analysis of the effect of distance from seed source. The number of randomly selected white spruce should have been proportional to cutblock age so that each cohort had an equal probability of being sampled in all cutblock ages.

The effect of substrate on white spruce growth could be more effectively investigated by limiting the study population to a narrow age range such as five to eight years. This would minimize the number of ephemeral seedlings and focus analysis on those most likely to survive to maturity. Measurement of the current leader and previous year's internode lengths would focus analysis on growth for the years in which the seedling could be thought of as truly established. Perhaps the greatest weakness in the present study is the exclusion of a vegetative competition assessment such as percent cover estimates by species of the top competitors for light. By measuring and including this factor in statistical analyses a clearer assessment of the effect of substrate type could be made. The competition status could also be linked to the current year leader length and allow investigation of the effects of various levels of vegetative competition.

The inability of the present study to detect any differences in climate-growth relationships of mature white spruce between pre and postdam periods may be due to the overriding influence of regional climate or the continuation of periodic high river stage in the postdam period (Figure 3-2). Investigations into the effect of hydrologic control of the Peace River may be more successfully carried out in a number of ways. Examination of climate-growth relationships of balsam poplar found on low elevation landforms

may demonstrate a change between pre and postdam periods. Investigation of the role of flooding in the recruitment of both white spruce and balsam poplar on these low elevation landforms could be carried out by examining the age distribution of these species in relation to known flood years. The hypothesis that recruitment is greater following flooding could be tested by comparing the relative abundance of regeneration in known flood years versus nonflood years.

APPENDIX A.

ORIGIN OF WHITE SPRUCE STANDS ON THE LOWER AND MIDDLE TERRACE LAND TYPES OF THE LOWER PEACE RIVER VALLEY

Introduction

Low intensity surveys of white spruce on the Peace River lowlands conducted by Lacate et al (1965) noted recent burns, soil charcoal both near the surface and at depth in alluvial deposits, burned snags, fire scars and even-aged stands as evidence of fire origin. These authors postulated that fire would result in the maintenance of pioneer vegetation, whereas flooding would allow succession to the next stage due to the improved moisture regime associated with sedimentation and terrace buildup. Jeffrey (1961) suggested that stand removal by catastrophic windthrow was also an agent of stand origin and that the deposition of alluvial soil by flood events may have aided stand regeneration after trees were killed by fire. Such general surveys did not specify the dominant disturbance type and frequency associated with the major land types as defined by Lacate et al (1965).

The objective of this study was to determine the fire frequency (and other disturbance frequency where possible) on the low and middle terrace land types through a stand origin study. It was hypothesized that stands on the middle terraces, especially when these forests were contiguous with upland forests, would be predominantly of fire origin and those at elevations within reach of flood waters (even low frequency flooding caused by ice jams), would be predominantly of alluvial deposit (flood) origin.

Materials and Methods

Study sites were within Wood Buffalo National Park from Fifth Meridian to the Boyer Rapids. The study was restricted to this area because the low terrace is much diminished in extent upriver outside of the Park, where it is largely represented by islands which have been harvested. About 80 potential stands were identified initially using aerial photographs and 1:50,000 topographic maps (minimum stand size was one hectare). Twenty four stands on the low terrace and twenty two stands on the middle terrace were field sampled. A point was randomly located in the central area of each stand. Increment cores were taken from the five largest diameter canopy dominants radiating out from the central point. Three additional cores were taken from canopy subdominants if there was a well defined subdominant tree layer. The cores were mounted on grooved wooded blocks and sanded to a smooth finish, then ring counts were performed under magnification. If all samples were of similar age the oldest sample was used to establish the date of stand origin. If a range of ages was found, the oldest sample age was used. If a minority of the samples were much older than the rest, then the oldest of the younger samples was used to date the stand origin.

The mechanism of stand origin was determined by interpreting stand conditions and soil profile data. The depths of the surface organic layer (both living and decomposing), buried organic layers, rotting

wood, ash beds, and charcoal were measured to the nearest centimetre by augering at randomly selected points within the stand to a depth of 1 metre or until frozen ground was reached. The depths of abrupt soil texture changes were also measured to the nearest centimetre. The presence of burned stumps found in situ was taken as evidence of a fire origin for the stand. Soil charcoal and/or ash beds were interpreted as evidence of fire origin, particularly if found at similar depths in several soil profiles. The presence of buried organic layers and/or rotted wood interspaced by layers of silt or clay combined with a lack of evidence of fire was interpreted as evidence of a flood origin. Abrupt changes in soil texture (i.e.; from silt/clay to sand) were also interpreted as evidence for a flood origin.

Results

Figure A-1 shows the age distribution for stands on each terrace level, while figure 1-1 shows the location, terrace level, origin mechanism, and age for all the stands sampled. On the basis of age:height relationships from other studies the ring count origin dates were increased by ten years to adjust for the time needed to attain breast height. On the low terrace the stand ages ranged from 4 years to 320 years. The distribution was binomial with groups of stands ranging from 10 to 80 years and 140 to 220 years. This would place stand origin in the years 1770 to 1850 and from 1910 to 1989. The middle terrace age distribution was a more normal curve with a maximum at about 160 years (origin dated about 1830). The large number of stands from the middle terrace in the 60 to 79 year age class is due partially to four stands of similar age (60 to 64 yrs). This suggests a peak in disturbance frequency at about 1919-1923 as the stands were not adjacent to each other.

A Wilcoxan two-sample test was used to determine whether the populations sampled were significantly different in their age distributions. The t statistic calculated was 10.9 while the critical value of t at the 0.01 significance level is 3.9; therefore the distribution of stand ages differs between the terrace levels. The origin of stands on the low terrace was classified as 54% (13 stands) due to fire and 46% (11 stands) due to flooding. On the middle terrace fire origin was assigned to 91% (20 stands) while flooding (i.e.; no evidence of fire) appeared to be associated with the origin of 9% (2 stands).

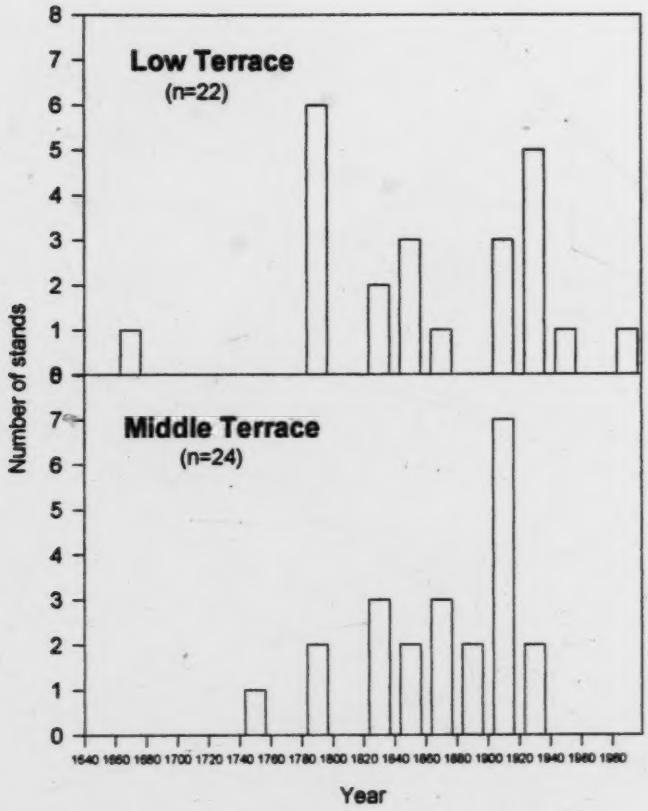

Figure A1. Age distribution of stands sampled in the Peace River Valley

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